EFFECTS OF NANOFLUIDS ON HEAVY VEHICLE SYSTEMS

Dileep Singh and Jules Routbort
Argonne National Laboratory

April 19, 2006

Contributors:
G. Chen
J. Hull
R. Smith
O. Ajayi

Rationale

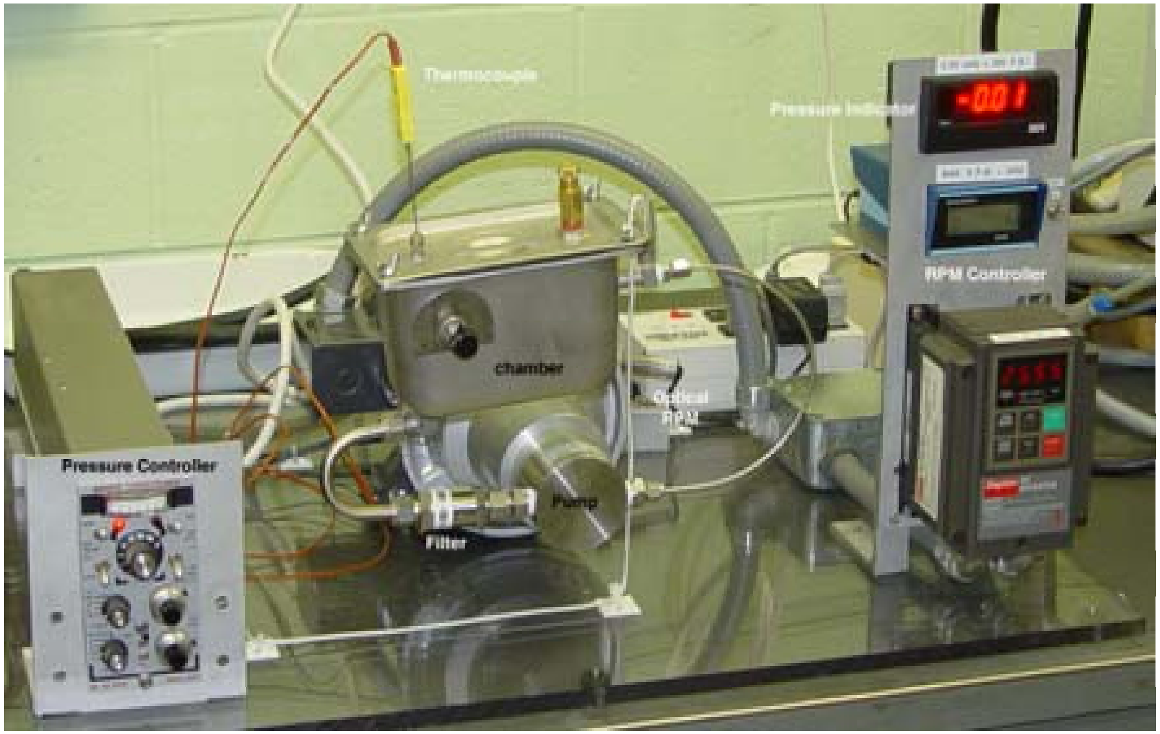
- Use of high-thermal conductive nanofluids for HV radiator systems can lead up to 10% reduction in radiator frontal area and consequently translate to as much as 5% fuel savings by reducing aerodynamic drag
  - Effect of nanofluid on radiator material is not known

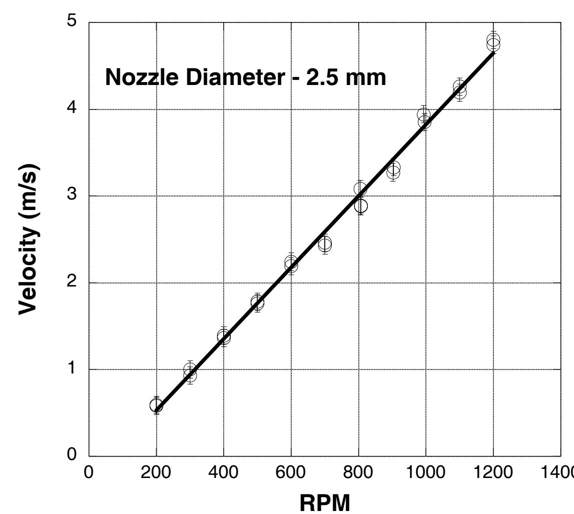
- Reduction of friction and wear reduces parasitic losses and can lead to >6% fuel savings
  - Applicability of nanofluids for tribological applications is not established

Objectives

- Determine if nanofluids degrade radiator systems
  - Develop apparatus/pumping system
  - Weight-loss measurements (or erosion rate) as a function of fluid velocity and impact angle
- Determine effect of nanofluids as a lubricant in moving components
  - Measure wear rates of steel on aluminum and steel on steel using nanofluids as lubricants
  - Particle loadings, speed, load
- Develop predictive model of nanofluid erosion and wear in engine components
- Establish the best nanofluid formulation(s) for wear and erosion applications

Liquid Erosion Test Rig





Nozzle diameter = 2.5 mm
V as high as 10 m/s can be achieved

Calibration (ethylene glycol/water)

Redesigned Liquid Erosion Setup

Additional pressure gages installed to monitor any changes in fluid velocity

Erosion – 50% Ethylene Glycol, 50% H_2O Aluminum 3003 – 50°C

Impact Angle (•)	Velocity (m/s)	Time (hrs)	Weight Loss (mg)
90	8.0	236	0 ± 0.2
90	10.5	211	0 ± 0.2
50	6.0	264	0 ± 0.2
50	10.0	244	0 ± 0.2
30	8.0	283	0 ± 0.2
30	10.5	293	0 ± 0.2

Baseline data established
No measurable erosion observed

Erosion – Trichloroethylene Gycol on Aluminum 3003 – 50°C

Impact Angle (•)	Velocity (m/s)	Time (hrs)	Weight Loss (mg)
90	7.6	238	0 ± 0.2
30	7.6	263	0 ± 0.2
90	9.6	242	0 ± 0.2
30	9.6	307	0 ± 0.2

Baseline data established
No measurable erosion observed

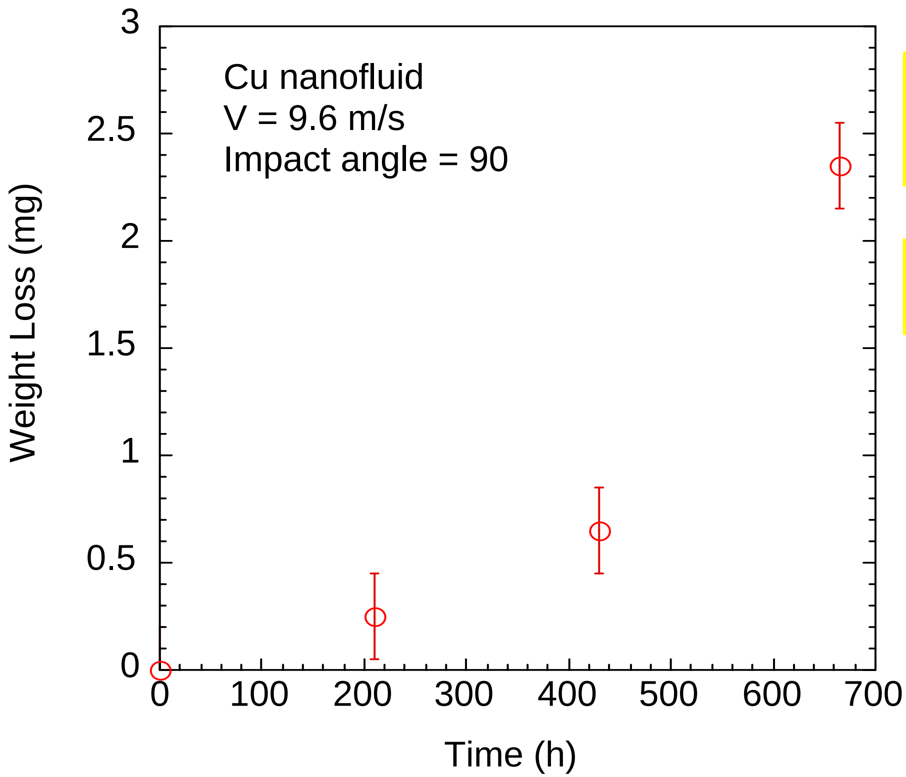
Erosion – Cu Nanoparticles in Tri-chloroethylene Glycol on Al 3003 - 50 °C

Impact Angle (•)	Velocity (m/s)	Time (hrs)	Weight Loss (mg)
90	4.0	217	0 ± 0.2
30	4.0	311	0 ± 0.2
90	7.6	341	0 ± 0.2
30	7.6	335	0 ± 0.2
30	9.6	336	0 ± 0.2

Cu in trichloroethylene (~0.02 wt%)

No measurable erosion observed

Erosion – Cu Nanoparticles in Tri-chloroethylene Glycol on Al 3003 - 50 °C



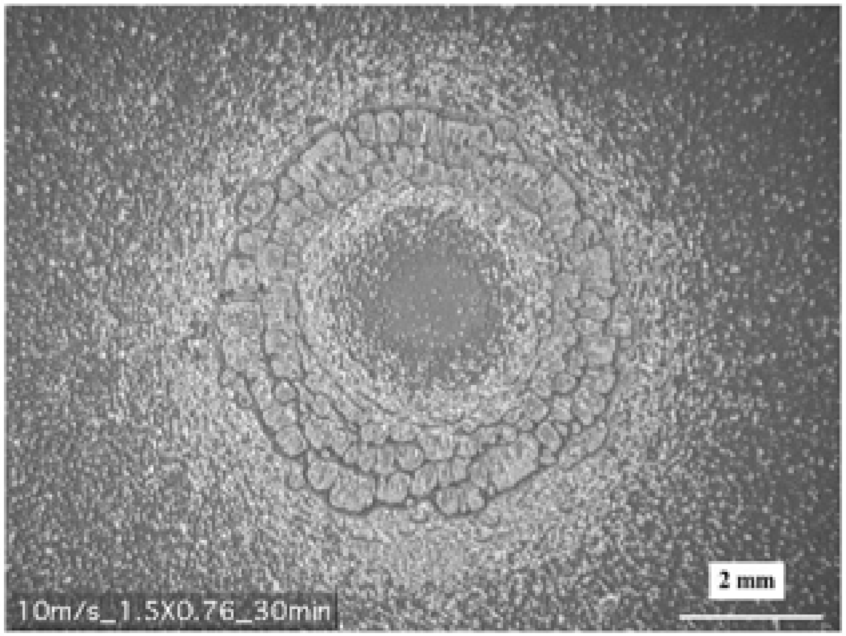
Erosion observed at V = 9.6 m/s
Impact angle = 90°

Erosion Rate (9.6 m/s) = 3.5×10^{-6} g/h

E.R. ~ V^2

Erosion Rate (1 m/s) = 3.5×10^{-8} g/h

Recession Rate – Cu Nanoparticles in Tri-chloroethylene Glycol on Al 3003 - 50 °C



Erosion Rate (1 m/s) = 3.5 x 10^{-8} g/h

Recession Rate (1 m/s) = ER/(density*t*A)

= 0.065 mils/yr

based on 2500 h/yr of engine operation

Damage zone formed on painted target at 90° impact by fluid jet

Recession Rate vs. Corrosion Rate for Typical Metal

Recession Rate (1 m/s) = 0.065 mils/yr
based on 2500 h/yr of operation

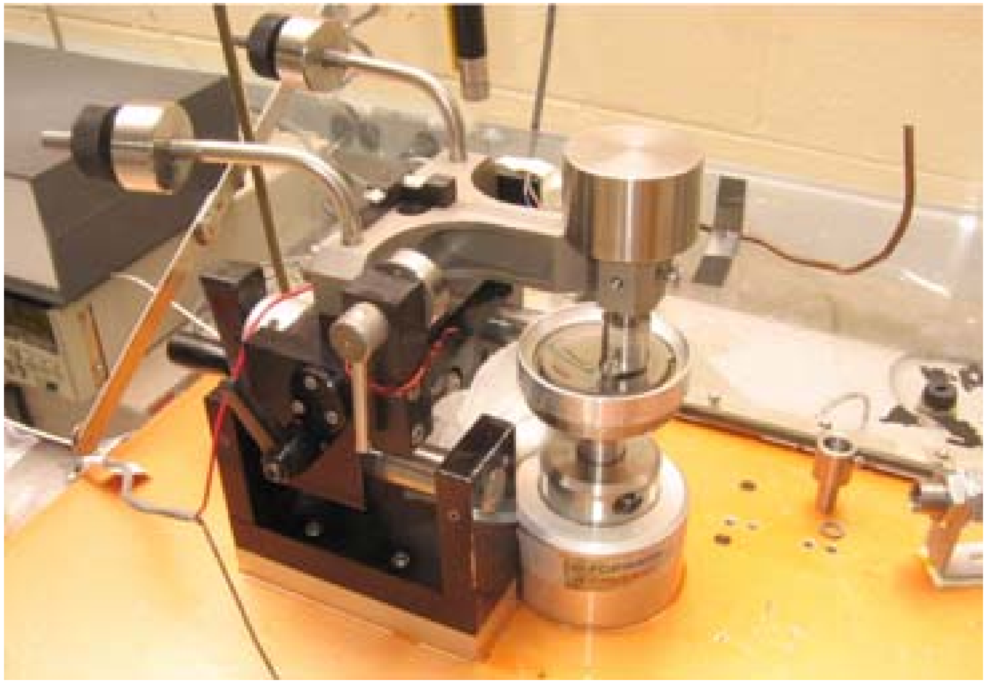
Typical corrosion rate of steel in water is
2 mils/yr

Recession rate of aluminum from Cu nanofluid (at typical radiator fluid velocity) is about 2 orders of magnitude lower than corrosion rates of steel in water!

Wear and Friction of Nanofluids

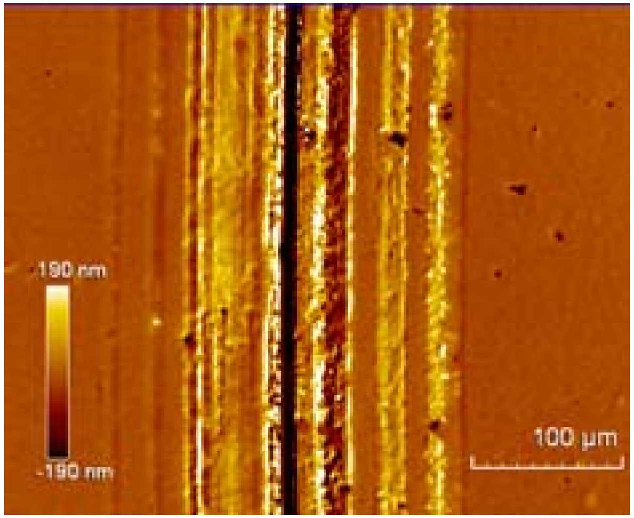
Ball-on-disk Tribotester

Disk (steel 4400) dia. = 2 in.
Ball (steel 5210) dia. = 0.5 in

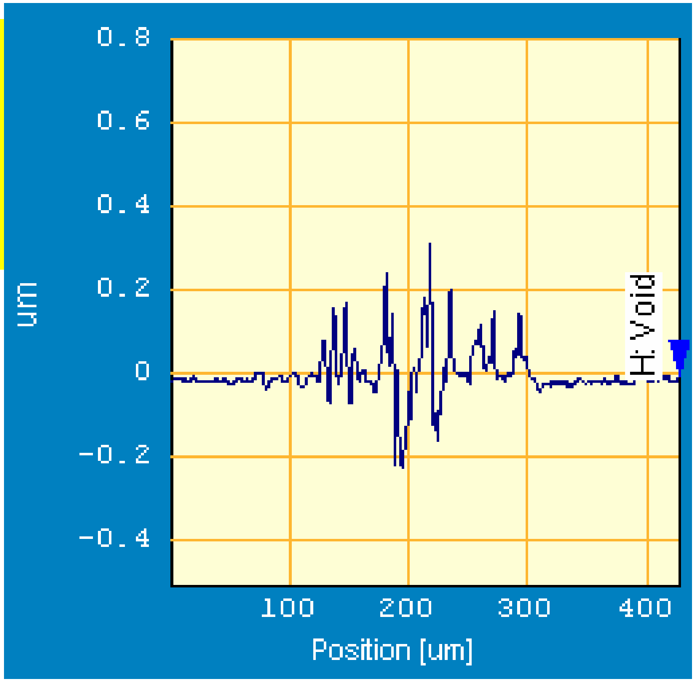


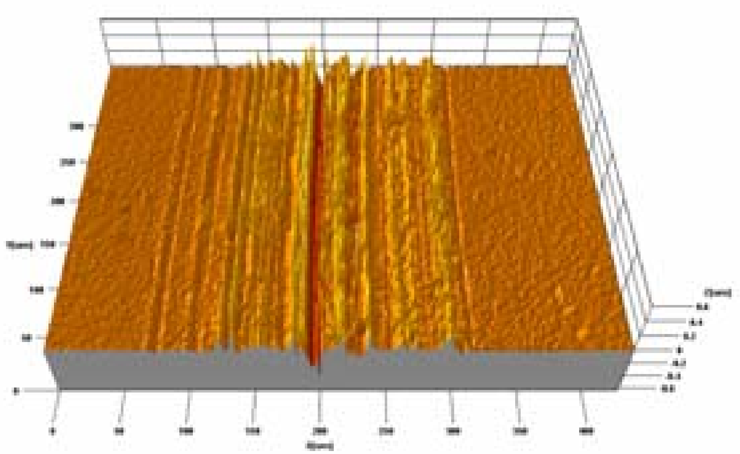
Cu in trichloroethylene (~0.02 wt%)
Alumina in water (0.5 & 1.5 vol.%)
Nanoparticle size ~ 25-40 nm

Steel on Steel: Tri-chloroethylene Glycol



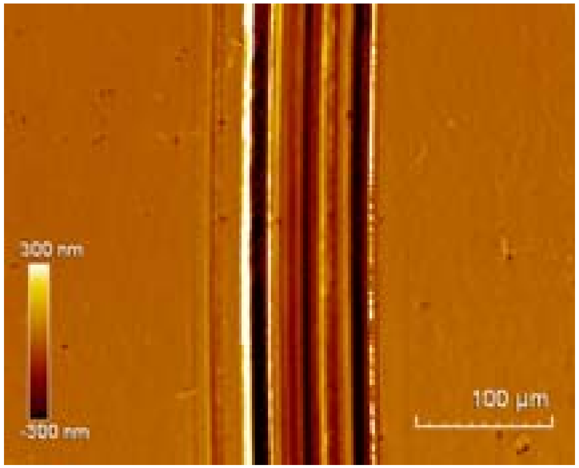
- Load = 2 N
- Track Dia. = 35 mm
- V = 0.1 m/s
- t = 3 h



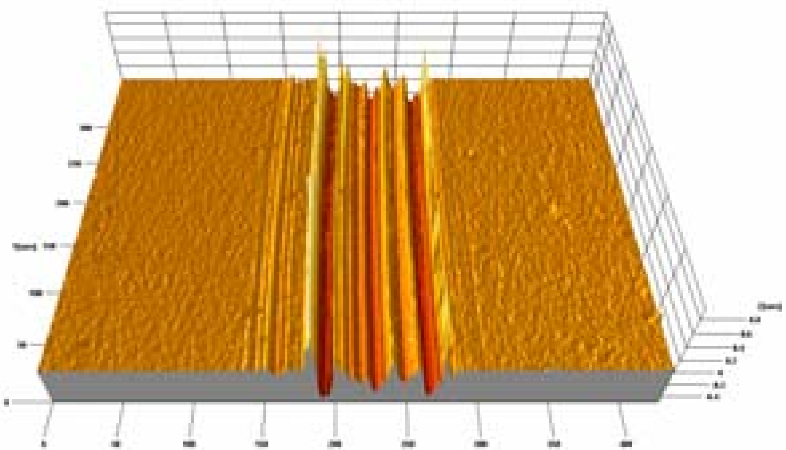


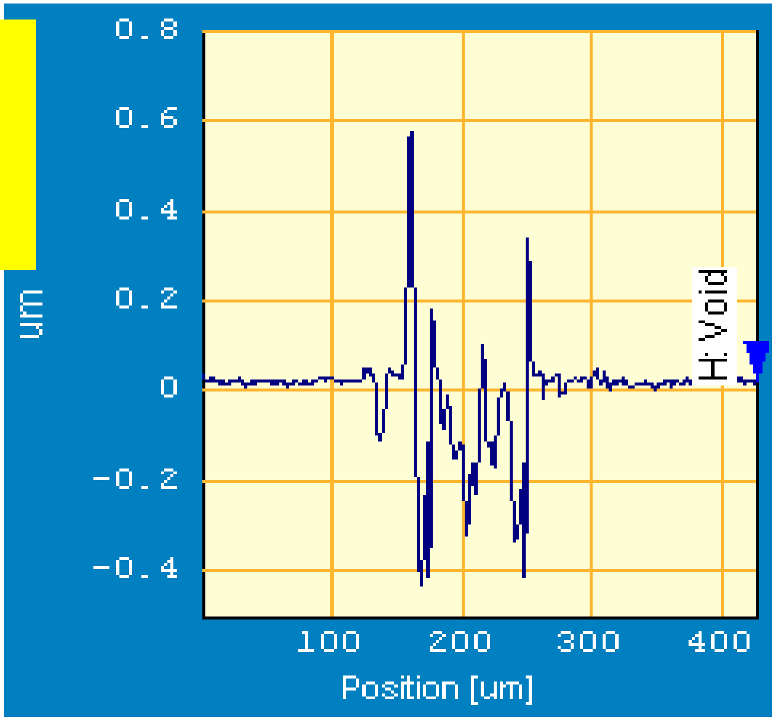
- Formation of surface layer
- Oxidative wear?
- Wear tracks ~ 200 µm wide

Steel on Steel: Cu Nanofluid (Tri-chloroethylene Glycol)



- Load = 2 N
- Track Dia. = 35 mm
- V = 0.1 m/s
- t = 3 h

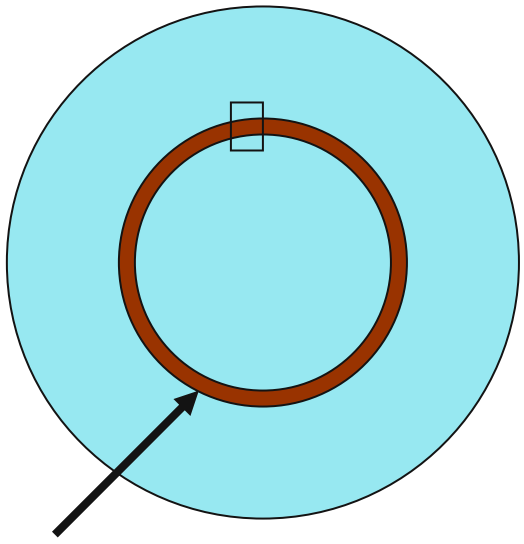




- Sharp wear tracks
- Abrasive wear/ploughing action
- Wear tracks ~ 100 µm wide
- Viscosity differences between nanofluid and base fluid?

Wear Rate

Using profilometer, material volume (M) removed is determined at several locations along the wear track



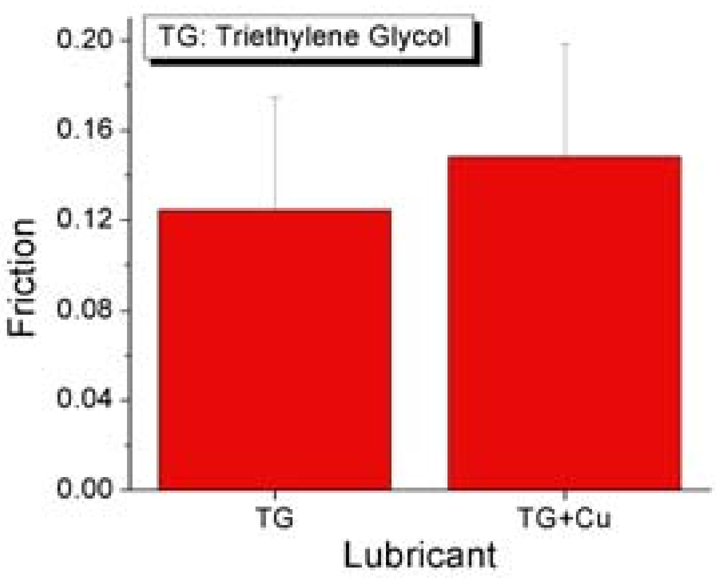
Wear rate = M/(L*P)

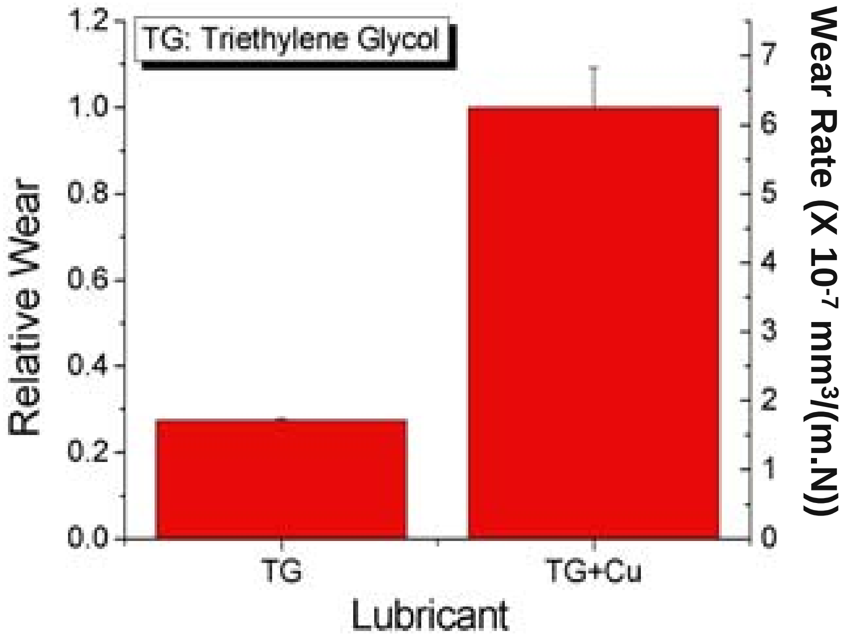
L = length of travel
P = force applied

Effect of Cu Nanofluid on Friction & Wear

Friction:

Wear:

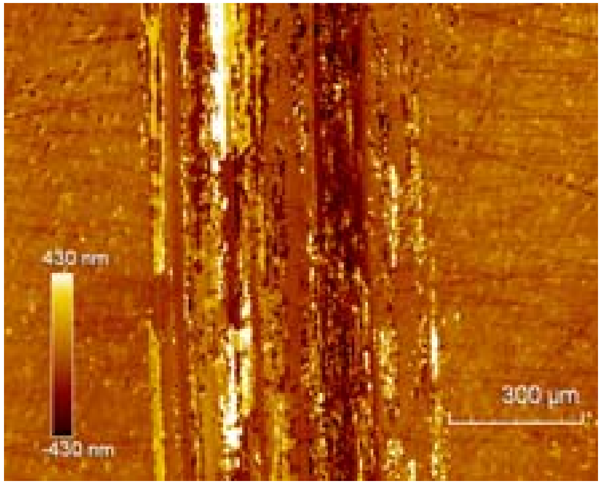


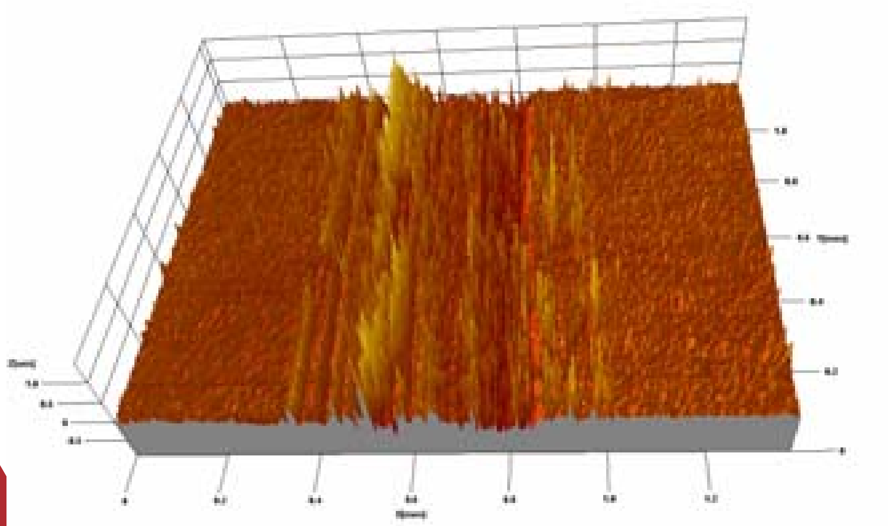


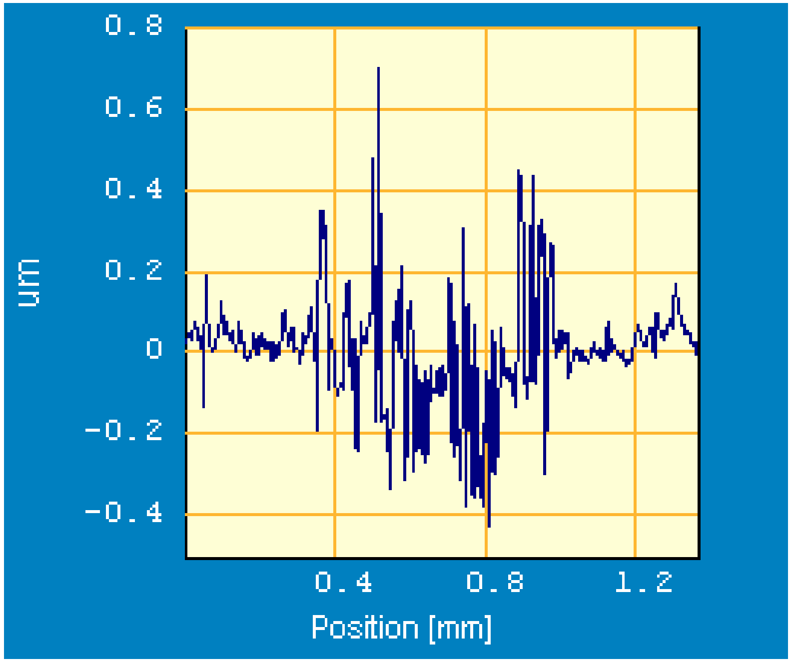
No significant difference in friction

Higher wear rate for Cu nanofluid
Cu --> CuO? leads to the abrasive wear?
Mild wear < 10^{-6} mm^3/m-N

Ball-on-Disk, Steel/Steel, Water - Profilometery



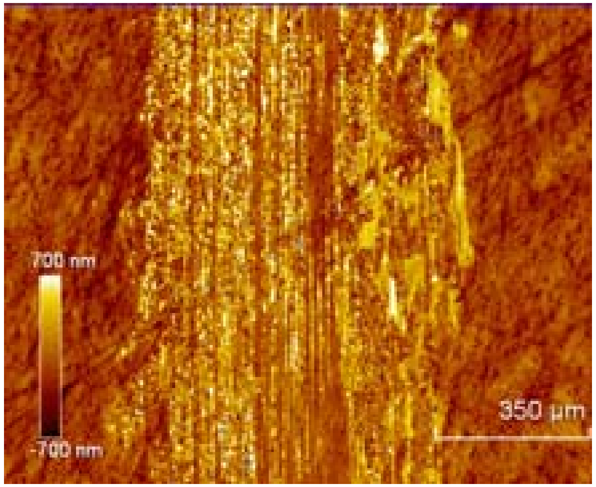


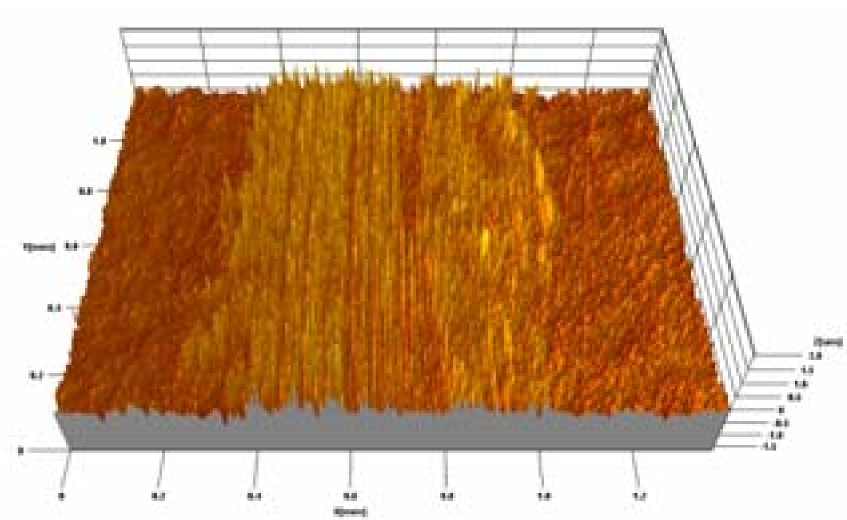


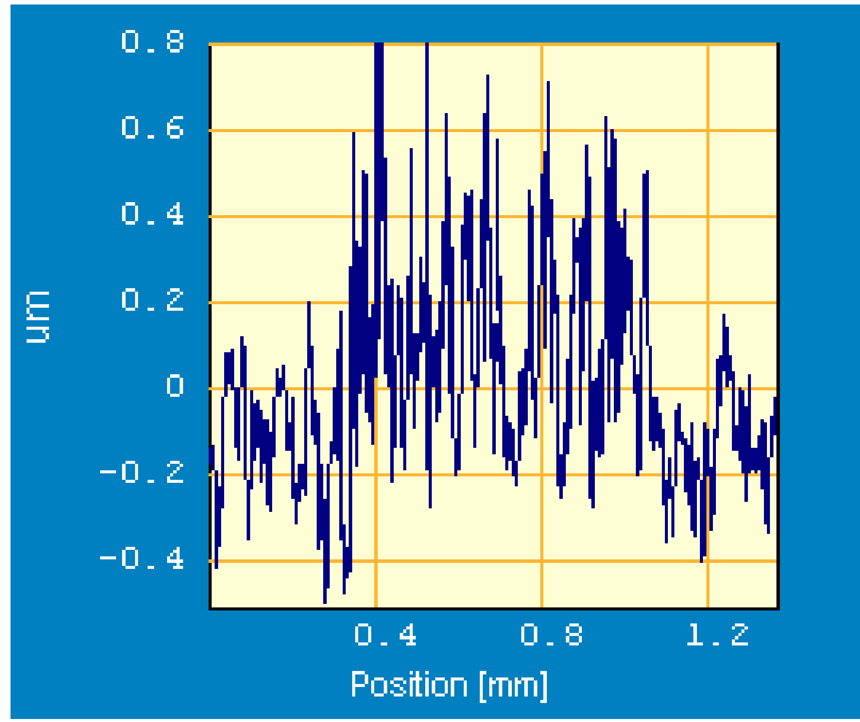
- Load = 2 N
- Track dia. = 35 mm
- V = 0.1 m/s
- t = 3 h

Typical metal/metal contact wear

Ball-on-Disk, Steel/Steel, Alumina Nanofluid 0.5 vol.% in Water - Profilometery



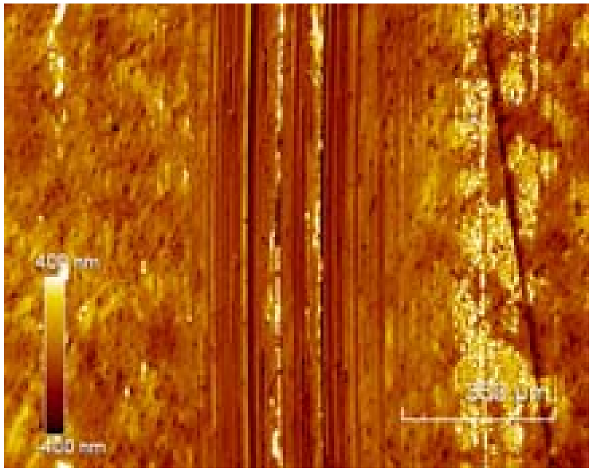


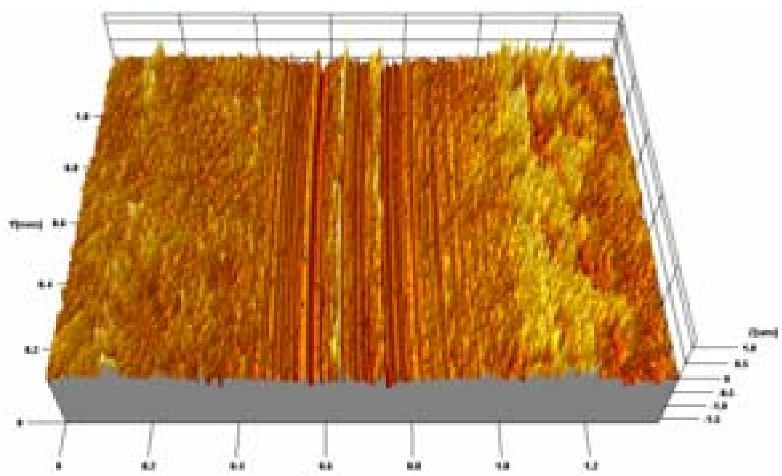


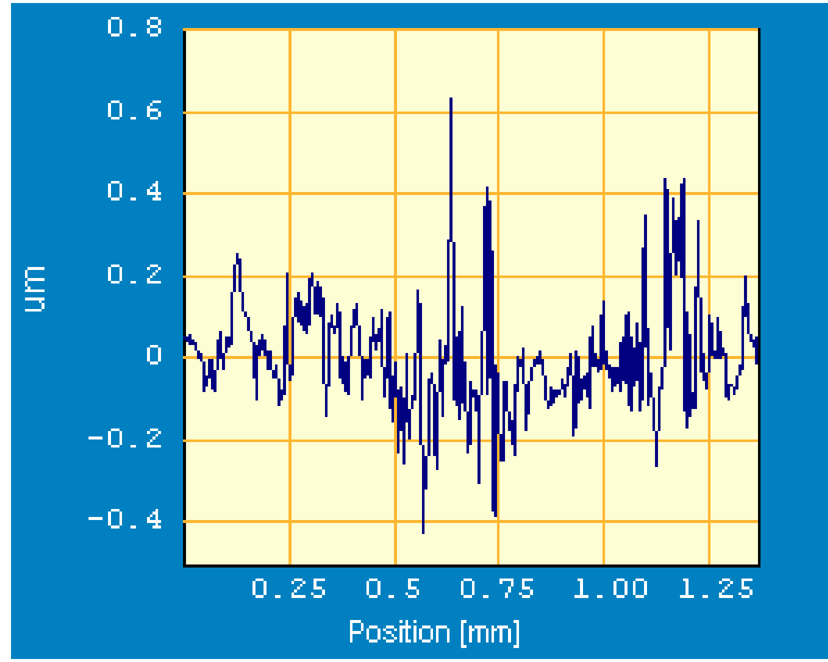
- Load = 2 N
- Track dia. = 35 mm
- V = 0.1 m/s
- t = 3 h

No material removal
Polishing action

Ball-on-Disk, Steel/Steel, Alumina Nanofluid 1.5 vol.% in Water - Profilometery





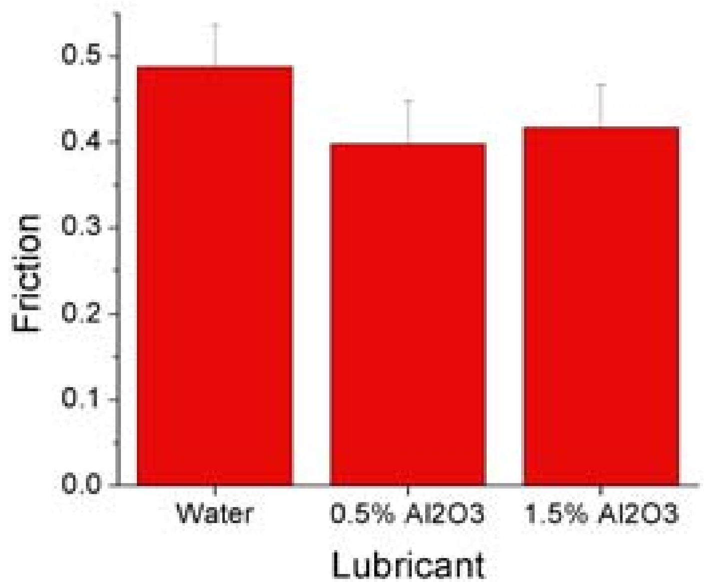


- Load = 2 N
- Track dia. = 35 mm
- V = 0.1 m/s, t = 3 h

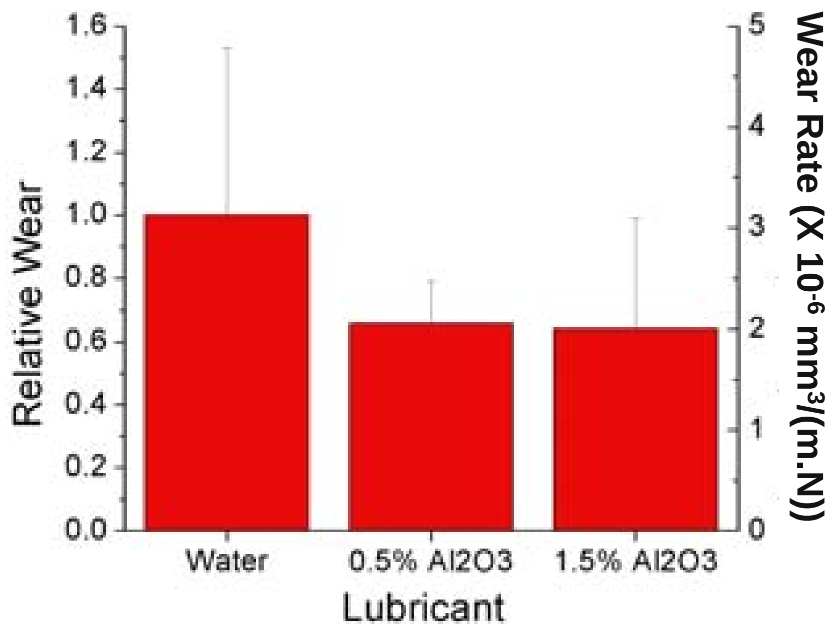
Wear tracks visible
Preliminary evidence of fatigue wear

Effect of Alumina Concentration in Nanofluid on Friction & Wear

Friction:



Wear:



Slightly decreased friction value for alumina nanofluids

Alumina nanofluids exhibit somewhat lower wear rate

Summary

- A test apparatus to study erosion by nanofluids has been designed, fabricated, and calibrated
- No erosion observed with base ethylene and tri-chloroethylene glycols up to velocities as high as 9 m/s and at 90°-30° impact angles
- Cu nanofluid showed erosion at V=9.6 m/s and angle of 90°; corresponding recession rate was 0.065 mils/yr of vehicle operation
- Preliminary investigation of the tribological properties of Cu and alumina nanofluids has been conducted
- Higher wear rate from Cu nanofluid as compared to base fluid is possibly due to oxidation of Cu nanoparticles
- Alumina nanofluids exhibited lower friction and wear rates as compared to base fluid. No significant difference in friction and wear behavior was observed for the two nano-particle loadings studied

Future Plans

- Complete erosion study using Cu nanofluids as a function of fluid velocity and impact angles – (9/06)
- Study erosion behavior using nanofluids with higher particle loadings (FY 07)
- Understand tribological behavior of nanofluids by detailed microstructural evaluation of the wear surfaces (FY 07)
- Conduct tribological tests using nanofluids with a wider range of particle loadings (FY 07)
- Develop predictive models for nanofluid wear and erosion in engine components/systems (FY 08)
- Establish the applicability of nanofluid(s) as a coolant for HV radiator systems as well as for tribological applications in engine systems (FY 08)
- Establish industrial collaborations to transfer the technology (FY 08)